

## Particleboard quality characteristics of saline jose tall wheatgrass and chemical treatment effect

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### Abstract

The objective of this research was to characterize the qualities (mechanical properties and water resistance) of particleboard made from saline Jose Tall Wheatgrass (JTW), *Agropyron elongatum*. For the JTW particleboards made with 4% polymeric methane diphenyl diisocyanate (PMDI), the mechanical properties and water resistance improved with the increase of particleboard density from 0.71 to 0.75 g/cm<sup>3</sup>. The particleboards with density of 0.74 g/cm<sup>3</sup> had similar mechanical properties of wood-based particleboards, except for lower internal bond strength. Among the particleboards made with particles of different initial moisture contents from 2% to 10%, the particleboard with the particles of 8% initial moisture content had the highest qualities. The pretreatment using NaOH solution to wash the JTW particles reduced the qualities of finished particleboards bonded with both PMDI and urea formaldehyde (UF) resins. Particleboards made with PMDI showed superior qualities than those made with UF, as shown by the measured contact angle results between the adhesives and JTW.

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### 1. Introduction

The demand for glued-wood composite products, such as particleboard, medium-density fiberboard and plywood, has recently increased dramatically throughout the world, especially for housing construction and furniture manufacturing (Sellers, 2000; Youngquist, 1999). The Food and Agricultural Organization (FAO) of the United Nations reported that the worldwide consumption of particleboards was 56.2 million cubic meters in 1998 (Youngquist and Hamilton, 2000). The 76 particleboard mills in North America produced 11 million cubic meters of particle-

boards, which accounted for 19% of the total wood composites produced (Sellers, 2000, 2001). According to a report from Kozlowski and Helwig (1998), the wood used for particleboard production was a significant portion of the 0.36 billion cubic meters of the wood that was consumed annually and the annual wood consumption is expected to reach about 0.47 billion cubic meters by 2010. The large amount of wood consumption could mean a high worldwide deforestation rate that can cause negative impacts on the environment. Therefore, increased interest has been seen in the production of particleboards from other biomass, such as grass, straw, plant, and agricultural residues.

Agricultural residues provide renewable and environmentally friendly alternative biomass resources for easing the high demand for woody materials (Kozlowski and Helwig, 1998; Sampathrajan et al., 1992). As a result, much

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research has been focused on making particleboards using rice straw, cotton stalks, sugar cane bagasse (Heslop, 1997; Pan and Cathcart, 2004), wheat straw (Han et al., 1998; Mo et al., 2003; Wang and Sun, 2002), sunflower stalks (Khristova et al., 1998), and maize husks and cobs (Sampathrajan et al., 1992).

Jose Tall Wheatgrass (JTW), *Agropyron elongatum*, has been used as pasture, silage or “standing hay” for cattle and upland game cover, especially in the winter (Sharp Bros Seed Co., 1997). It has a high tolerance to saline, saline-alkali or alkali soils and can be used for the reclamation of saline-alkali lands. Currently, JTW is being grown in San Joaquin Valley (SJV), California, to help manage saline subsurface drainage water in arid land irrigated agriculture by transpiring water and concentrating salt from drainage water. However, little information is available about the properties of saline herbaceous particleboards, which may have many potential applications. The composition of JTW used for this research was analyzed (Hazen Research, Inc., Golden, CO) and showed that JTW had about 9% ash, which primarily contained  $\text{SiO}_2$ ,  $\text{Na}_2\text{O}$ , and  $\text{K}_2\text{O}$ . The JTW also had oxidants, such as  $\text{CuO}$ ,  $\text{CrO}_3$  and  $\text{As}_2\text{O}_5$ . It has been reported that the presence of such oxidants could significantly improve the mechanical properties and dimensional stability of particleboard (Huang and Cooper, 2000; Nemli et al., 2004). Therefore, the JTW is expected to be a desirable raw material in particleboard manufacturing.

Wang and Sun (2002) and Papadopoulos et al. (2002, 2004) reported that the density of particleboards made from wheat straw, coconut chips, and bamboo chips significantly affected the particleboard properties. The initial moisture content (MC) of raw materials could also result in quality changes of the particleboards. The tensile strength of particleboard decreased from 4888 to 3967 kPa when the initial MC of wheat straw increased from 10% to 40% (Mo et al., 2001). In addition, particleboard quality depends on the properties of adhesives and bonding capability with fibers or particles. The contact angle between the outer surface of straw and the adhesive has been used as an indicator of binding capability (wettability) of an adhesive on fibers (Boquillon et al., 2004). Urea-formaldehyde (UF) has been the major adhesive for wood-based particleboards, but it is not effective for bonding wheat straw due to the relative high concentrations of extractives, such as wax and some alkaline substance, on the surface of wheat straw (Heslop, 1997; Vick, 1999). Wheat straw particleboard bonded with polymeric methane diphenyl diisocyanate (PMDI) had mechanical properties 3–10 times better than that with UF (Heslop, 1997), but the cost of PMDI was about ten times that of UF (Cathcart, 2003; Zhang et al., 2003). The PMDI-bonded panels have much higher production costs than the UF-bonded panels. Therefore, the cost and type of adhesive are concerns in the particleboard industry (Zhou and Mei, 2000). The mechanical properties of wheat straw particleboards bonded by UF can be improved by removing wax and ash from the wheat

straw surface through bleaching with oxidizing agents and alkaline (e.g.  $\text{H}_2\text{O}_2$  and  $\text{NaOH}$ , respectively) (Mo et al., 2003; Wu and Gatewood, 1998).

The objectives of this study were to (1) characterize the mechanical properties and water resistance of particleboard made from JTW as affected by adhesives (PMDI and UF),  $\text{NaOH}$  treatment, initial MC of JTW particles, and density of particleboards; and (2) determine the contact angles between the adhesives (PMDI and UF) and JTW (with and without  $\text{NaOH}$  treatment) and investigate the relationship between the contact angle and particleboard properties.

## 2. Methods

### 2.1. Materials

The UF resin (C-TH39, 65.6% solid content) and PMDI (100% solid content) were used as adhesives for making the particleboards in this study. They were purchased from Borden Chemical Company (Hope, AR) and Bayer Polymers LLC (Pittsburgh, PA), respectively. Both ammonium sulfate  $[(\text{NH}_4)_2\text{SO}_4]$  and sodium hydroxide ( $\text{NaOH}$ ) were purchased from Fisher Scientific Chemical Co. (Fair Lawn, New Jersey).

The JTW used in the study was collected from Red Rock Ranch (RRR) located on the Westside of the San Joaquin Valley (SJV), California. The moisture content (MC) of as-received JTW was determined to be about 11% (wet base), i.e.,  $(\text{wet mass} - \text{dry mass}) / \text{wet mass} \times 100\%$  (D4442-92, American Society of Testing and Materials, 1997). All reported moisture contents in this study were on wet basis unless specified otherwise. The JTW was cut, field dried, and baled in May 2004, with an average straw length of 0.5 m. Bales were stored indoors in an un-air-conditioned building until used. Bales were milled into particles using a hammer mill (Model C269OYB, Franklin Co. Inc., Buffton, IN) equipped with a screen that has 0.32 cm opening. After milling, the fiber particles were classified into three groups based on the particle size, greater than 10, 10–40 and less than 40 mesh, using a sieve shaker (RO TAP, The W. S. Tyler Company, Cleveland, OH) with corresponding sieves (Newark Wire Cloth Co.). The particles of 10–40 mesh were further dried to 8% MC using ambient air and then stored in plastic bags kept in the Biomass Laboratory at University of California, Davis, under  $62 \pm 1\%$  RH and  $22 \pm 1^\circ\text{C}$  until being used.

### 2.2. NaOH treatment for jose tall wheatgrass

The 1 M  $\text{NaOH}$  solution was prepared with  $50^\circ\text{C}$  distilled water. The JTW particles were soaked in  $\text{NaOH}$  solution at a ratio of 1 g to 10 ml at  $50^\circ\text{C}$  for 30 min. The treated JTW particles were washed three to five times using  $50^\circ\text{C}$  water until the pH value of washing water reached about 7. The washed particles were then dried in ambient air to a MC of 8%.

### 2.3. Experimental design and data analysis

The PMDI content (based on the dry weight of JTW particles) and MC of particles were controlled at 4% and 8%, respectively, in order to determine the effect of density on the properties of JTW particleboard. The particleboards with five densities (0.71, 0.72, 0.73, 0.74 and 0.75 g/cm<sup>3</sup>) were made for the study. The preliminary test results showed that the properties of particleboards with density of 0.73 g/cm<sup>3</sup> were sufficient to meet the requirements of the M-2 mechanical properties for industrial usage. Therefore, the density of 0.73 g/cm<sup>3</sup> was chosen for all the subsequent experiments unless specified otherwise.

The initial moisture content of JTW particles was adjusted to 2%, 4%, 6%, 8% and 10% by oven drying and used to produce particleboards with density of 0.73 g/cm<sup>3</sup> using 4% PMDI based on the dry weight of JTW particles and the effect of MC on the properties of finished particleboards was determined. The tests with a 2 × 2 factorial experimental design were conducted to determine the effect of adhesives and NaOH treatment of JTW on the mechanical strength and water resistance of particleboards. The two factors were PMDI and UF, with two levels of NaOH treated and non-treated particles. The UF and PMDI resin contents were kept at 7% and 4%, respectively, as suggested in the literatures (Mo et al., 2003; Youngquist, 1999). The initial MC of particles and final density of particleboards were 8% and 0.73 g/cm<sup>3</sup>, respectively.

For all the experiments described above, data were analyzed using a SAS software package (SAS Institute, Raleigh, N.C., 1992). Analysis of variance (ANOVA) and least significant difference (LSD) ( $\alpha=0.05$ ) were used to differentiate the treatment means. All reported values are the average of three replicates.

### 2.4. Particleboard manufacturing

Particleboards were fabricated according to the procedures outlined in the *Wood Handbook* (Youngquist, 1999). The UF or PMDI resin was mixed with the JTW particles using a mixer (Model KP267XBK; KitchenAid, Greenville, OH) for 8 min at room temperature (20 ± 2 °C). When UF resin was used, 1% (w/w) (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> based on the solid weight of UF was used as a curing catalyst.

The particles with resin were prepressed into a single layer mat in a 22.8 cm × 22.8 cm wood mold before further pressed using a hot press (Model 3891 Auto “M”, Carver, Inc., Wabash, IN) to make the final particleboard. The hot press used removable steel stops to achieve a constant thickness of particleboard. For PMDI bonded particleboards, the pressure, temperature and time were set at 2 MPa, 140 °C, and 8 min, respectively (Mo et al., 2003). For UF particleboards, 2 MPa, 160 °C, and 4 min were used (Mo et al., 2003; Youngquist, 1999). The thickness of the finished particleboards was 0.53 cm. The particleboards were trimmed to avoid edge effects and then cut into various sizes for property evaluation.

### 2.5. Evaluation of particleboard properties

Mechanical properties, including modulus of rupture (MOR), modulus of elasticity (MOE), internal bond strength (IB), tensile strength (TS), water absorption (WA), and thickness swelling (THS) were evaluated to assess particleboard qualities. These properties, the quality indicators, were measured for each finished particleboard using the methods described in the following sections.

#### 2.5.1. Mechanical properties

Finished particleboards were cut to various specifications according to ASTM standard method (D1037-99, American Society of Testing and Materials, 1999). Rectangular 3.8 cm × 15.2 cm and 5.1 cm × 17.8 cm pieces were used for TS determination and three point bending measurement of MOR and MOE, respectively. The 5.1 cm × 5.1 cm pieces were used for IB measurement. Prior to testing, the specimens were conditioned for 72 h in a Fisherbrand® Desiccator Cabinet maintained at 65% RH and 20 °C to achieve equilibrium moisture content (EMC) of 3.9% (Rowell et al., 1995). The mechanical properties were determined using an Instron testing machine (Model 1122; Instron Corporation, Canton, MA) with movable crosshead speed of 4 mm/min for TS test and 5 mm/min for three point bending and IB tests.

#### 2.5.2. Water absorption and thickness swelling

Water absorption and thickness swelling were determined according to the ASTM standard method (D1037-99, American Society for Testing and Materials, 1999). To determine short- and long-term absorption and thickness swelling properties, particleboards were cut into 15.2 cm × 15.2 cm squares and soaked in water at room temperature (20 ± 2 °C) for both 2 h and 24 h. The thickness and weight of the particleboard samples were measured before and immediately after soaking. The water absorption and thickness swelling were calculated as ratios of absorbed water and increased thickness to the values before soaking, respectively, and expressed as percentages.

#### 2.5.3. Density of finished particleboard

The particleboard was first conditioned at 65% RH and 20 °C for 72 h. The particleboard volume was calculated based on its thickness, width, and length measured with a digital caliper (500–196<sup>CE</sup>, MyCAL CD-6CS, Mitutoyo Inc.). The particleboard density was calculated as the ratio of the mass to the volume of the board.

### 2.6. Contact angle measurements

Contact angles between adhesives and JTW (treated and untreated) were measured using a contact angle goniometer (Model 100, Ramé-hart Instrument Co., Netcong, NJ, USA) to determine the wettability of the adhesives (UF and PMDI) on JTW particle surface under standard conditions (50% RH at 23 °C) (Boquillon et al., 2004). Due to the

structural difference between JTW and wheat straw, the inner surface of JTW leaf sheath was more visibly glossy than outer surface, which indicated that the inner surface had more wax than outer surface. Therefore, the inner surface was used for contact angle measurement. Relatively large leaf sheaths of JTW flake were flattened and cut into 1 cm × 3 cm rectangular pieces. The outer surface of the piece was attached to a 5 cm × 5 cm square glass using epoxy resin. After attachment, 5 µl of resin was dropped onto the JTW inner surface by syringe. The contact angle between JTW inner surface and adhesive, UF or PMDI, was then observed and recorded every 5 s for a 2 min period.

### 3. Results and discussion

#### 3.1. Effect of density on particleboard qualities

The qualities of particleboards were significantly improved with the increase of particleboard density (Table 1). Compared to low density particleboards, high density particleboards had lower porosity so that particles and adhesives can interact with each other more easily to form stronger crosslink. In particleboard industry, choosing proper particleboard density is a very important step and a proper density can be determined based on the intended application requirements (Youngquist, 1999). For example, particleboards with low density often are used as soundproofing materials. The JTW particleboards with a density of 0.72 g/cm<sup>3</sup> met the requirements of mechanical properties of grade M-S particleboard for commercial use (Table 2) (Composite Panel Association (CPA, 1999)). Meanwhile, their MOR (16.6 MPa), MOE (1936.8 MPa) and TS (10.26 MPa) were slightly lower than the MOR (19.6 MPa), MOE (2052.4 MPa) and TS (11.59 MPa) of Athel (*Tamarix aphylla*, L) wood particleboards (Zheng et al., 2006). The JTW particleboard with a density of 0.73 g/cm<sup>3</sup> was strong enough to meet the M-2 mechanical requirement for industrial application. Schneider et al. (1996) recommended property requirements for furniture boards of IB greater than 0.4 MPa, THS (24 h) less than 25%, and WA (24 h) less than 60%. When the density increased to 0.74 g/cm<sup>3</sup> or higher, the qualities of JTW particleboards exceeded the minimum requirements for furniture boards.

Table 2

IB, MOE, MOR and thickness swelling values required to meet ANSI A208.1

Usage	Grade	MOR (MPa)	MOE (MPa)	IB (MPa)	THS (%) <sup>a</sup>
Commercial	M-1	11.0	1725	0.4	8
Commercial	M-S	12.5	1900	0.4	8
Industrial	M-2	14.5	2225	0.45	8
Industrial	M-3	16.5	2750	0.55	8

<sup>a</sup> THS standard is special for manufactured home decking particleboard.

#### 3.2. Effect of particle moisture content on the particleboard qualities

The initial MC of JTW particles had significant effects on the qualities of finished particleboards. When the initial MC increased from 2% to 8%, the qualities of particleboards were improved (Table 3). However, as the MC increased from 8% to 10%, the MOR and MOE significantly decreased by 7.8 and 757.4 MPa, respectively, and both TS and IB decreased by about 50%. These results are consistent with those of wheat straw particleboard reported by Mo et al. (2001) and Sauter (1996). It appears that 8% MC was an optimal initial MC of the JTW particles for producing high strength particleboards with 4% PMDI.

The properties of particleboards bonded by PMDI depend on both reactions of PMDI with water and hydroxyl groups of JTW (Simon et al., 2002). PMDI could not be completely cured at initial MC less than 8% because PMDI could not penetrate JTW well enough to form polyurea and/or polyurethane crosslink among JTW particles. For the particleboard with 10% initial MC, however, it was observed that blow occurred was due to the high vapor pressure produced and accumulated in the particleboard during the hot press process. In addition, the PMDI might form amine instead of polyurea because too much water could stop the formation of polyurea from the reaction between PMDI and amine. In other words, too much water led to unnecessarily high decomposition of PMDI, thus resulting in weak adhesive network. The adverse effect of high MC of particles could be partially reduced by increasing the press time. Decreasing the pressure releasing rate can help prevent panels from blow. Reducing the size of finished particleboards can also be effective method to reduce the vapor build-up in the particleboards. Based on

Table 1

Properties of particleboard with different densities

Density (g/cm <sup>3</sup> )	MOR (MPa)	MOE (MPa)	TS (MPa)	IB (MPa)	WA (2 h) (%)	WA (24 h) (%)	THS (2 h) (%)	THS (24 h) (%)
0.71	12.4 ± 0.4e	1710.2 ± 1.8e	9.39 ± 0.03e	0.25 ± 0.03e	19.67 ± 0.03a	57.13 ± 0.04a	19.04 ± 0.06a	40.45 ± 0.08a
0.72	16.6 ± 0.3d	1936.8 ± 1.3d	10.26 ± 0.15d	0.41 ± 0.03d	19.05 ± 0.25b	55.82 ± 0.41b	16.07 ± 0.12b	39.49 ± 0.51a
0.73	18.1 ± 0.2c	2291.3 ± 1.8c	11.08 ± 0.04c	0.62 ± 0.03c	15.21 ± 0.24c	44.51 ± 0.55c	13.30 ± 0.55c	26.74 ± 1.02b
0.74	19.6 ± 0.2b	2313.3 ± 2.8b	12.93 ± 0.07b	0.78 ± 0.03b	14.62 ± 0.12d	40.65 ± 1.01d	10.45 ± 0.06d	22.05 ± 0.07c
0.75	21.7 ± 0.4a	2380.1 ± 1.6a	13.66 ± 0.31a	1.04 ± 0.06a	13.07 ± 0.14e	36.93 ± 0.14e	9.20 ± 0.08e	20.55 ± 0.78c

Data are mean ± standard deviation of triplicates tests; values within the same column followed by different letters are significant different at  $P < 0.05$ ; Initial MC – 8%; PMDI resin content – 4%; Particles – untreated; WA – water absorption; THS – thickness swelling.



Table 3  
Particleboard properties made from JTW particles with different initial MC

MC (%)	MOR (MPa)	MOE (MPa)	TS (MPa)	IB (MPa)	WA (2 h) (%)	WA (24 h) (%)	THS (2 h) (%)	THS (24 h) (%)
2	13.3 ± 0.7d	1683.5 ± 2.7d	7.93 ± 0.02c	0.43 ± 0.02c	25.79 ± 0.10a	64.04 ± 0.57a	18.20 ± 1.01b	46.19 ± 1.71a
4	15.9 ± 0.5b	1854.6 ± 2.4c	8.55 ± 0.04b	0.49 ± 0.05bc	20.96 ± 0.64b	58.94 ± 0.60b	16.87 ± 0.32bc	40.41 ± 0.58b
6	16.5 ± 0.5b	2017.5 ± 5.0b	10.98 ± 0.11a	0.53 ± 0.04ab	18.26 ± 0.08c	52.35 ± 1.01c	15.46 ± 0.64c	37.10 ± 0.56c
8	18.1 ± 0.2a	2291.3 ± 1.8a	11.08 ± 0.04a	0.62 ± 0.03a	15.21 ± 0.24d	44.51 ± 0.55d	13.30 ± 0.55d	26.74 ± 1.02d
10	10.3 ± 0.6c	1533.9 ± 2.8e	5.29 ± 0.05d	0.31 ± 0.01d	26.64 ± 0.57a	64.79 ± 0.58a	20.22 ± 0.98a	41.66 ± 1.51b

Data are mean ± standard deviation of triplicates tests; values within the same column followed by different letters are significant different at  $P < 0.05$ ; Particleboards: 4% PMDI, density of 0.73 g/cm<sup>3</sup>, untreated particles.

the quality results of particleboards with different initial moisture contents, 8% MC was used to study the effect of NaOH treatment on particleboard quality.

### 3.3. Effect of NaOH treatment on particleboard qualities

In general, particleboards manufactured from NaOH treated particles had lower qualities than those made from untreated particles (Table 4). But there were no significant differences in either MOR and IB of PMDI-bonded particleboard or IB of UF-bonded particleboards. For PMDI-bonded particleboard, the NaOH treatment reduced the MOE and TS significantly by 570.5 and 1.47 MPa, respectively. The short and long term water absorption and thickness swelling, however, increased by about 200% compared to the particleboard with untreated particles (Table 4). Compared with PMDI-bonded particleboards, the quality changes of UF-bonded particleboards showed similar trends. It is believed that the NaOH may have reacted with some components of JTW and changed the characteristics of the surface and/or the internal structure of JTW, which prevented the adhesives from bonding with JTW particles effectively. However, it has been reported that the NaOH did improve the wettability of both PMDI and UF, which theoretically and actually improved the bonding (Mo et al., 2001, 2003; Wang and Sun, 2002; Wu and Gatewood, 1998). It is likely that the residual NaOH accelerated the decomposition of PMDI, as hydroxyl anion is a stronger nucleophile than water. It is well known that UF resin is cured at an acidic pH (Xing et al., 2004). The residual NaOH increased the pH value and buffer capacity of JTW, which will definitely interfere with the curing of the pH-sensitive UF leading to worse qualities of UF-bonded particleboard (Sauter, 1996).

Regardless of the NaOH treatment, the qualities of particleboards bonded with PMDI were better than those

bonded with UF at the tested adhesive levels. The MOR and TS of PMDI-bonded particleboards were about 3–4 times and 9–10 times, respectively, greater than those of the UF-bonded particleboards. The PMDI-bonded particleboards had much lower short and long term water absorption and thickness swelling compared to UF-bonded particleboards. Compared with UF, PMDI was more effective in wetting the surface of the JTW, which enhanced chemical bonding through hydrogen bonds and polyurethane covalent bonds. The isocyanate groups of PMDI could also react with water in the JTW to generate cross-linked polyureas for strong mechanical bonding (Chelak and Newman, 1991). In contrast, the water-based UF could not effectively wet the JTW surface, penetrate, and bond to the JTW hydroxyl groups due to the presence of hydrophobic and inorganic silica on the JTW surface (Hague et al., 1998).

### 3.4. Contact angle

Contact angle measurements between the JTW inner surface and the adhesives confirmed the results of Section 3.3 (Table 4). As shown in Fig. 1, for untreated JTW, the initial contact angle of UF was 82° compared with 41° for PMDI. The results indicate that the wettability of the JTW by PMDI was much higher than that by UF because the PMDI molecules were small (Mo et al., 2001). The poor wetting between JTW and UF partially explains the poor particleboard qualities. For both adhesives, the contact angle reduction was 1° after 2 min, indicating a very small amount of adhesive absorbed by the JTW. This could be attributed to the low wettability caused by extractives such as hydrophobic wax and inorganic silica at the JTW inner surface. After the NaOH treatment, the initial contact angle was reduced by 2° and 12° for PMDI and UF, respectively, indicating that the effect of NaOH treatment for UF was

Table 4  
Effect of NaOH treatment on particleboard mechanical and water resistance properties

Adhesives	Treated method	MOR (MPa)	MOE (MPa)	TS (MPa)	IB (MPa)	WA (2 h) (%)	WA (24 h) (%)	THS (2 h) (%)	THS (24 h) (%)
PMDI	Untreated	18.1 ± 0.2a	2291.3 ± 1.8a	11.08 ± 0.04a	0.62 ± 0.03a	15.21 ± 0.24a	44.51 ± 0.55a	13.30 ± 0.55a	26.74 ± 1.02a
PMDI	NaOH	18.9 ± 0.2a	1720.8 ± 4.4b	9.61 ± 0.06b	0.61 ± 0.05a	34.33 ± 0.25b	90.40 ± 0.57b	24.27 ± 0.78b	47.25 ± 2.61b
UF	Untreated	6.1 ± 0.6b	1312.9 ± 4.8c	1.98 ± 0.08c	0.13 ± 0.04b	65.48 ± 0.21c	139.84 ± 0.41c	55.13 ± 0.37c	94.13 ± 2.64c
UF	NaOH	4.4 ± 0.4c	1256.6 ± 1.1d	1.09 ± 0.04d	0.13 ± 0.01b	89.16 ± 1.53d	161.03 ± 0.26d	67.28 ± 0.85d	101.44 ± 1.91d

Data are mean ± standard deviation of triplicates tests; values within the same column followed by different letters are significant different at  $P < 0.05$ ; PMDI – 4%; UF – 7%; Particle initial MC – 8%; Particleboard density – 0.73 g/cm<sup>3</sup>.

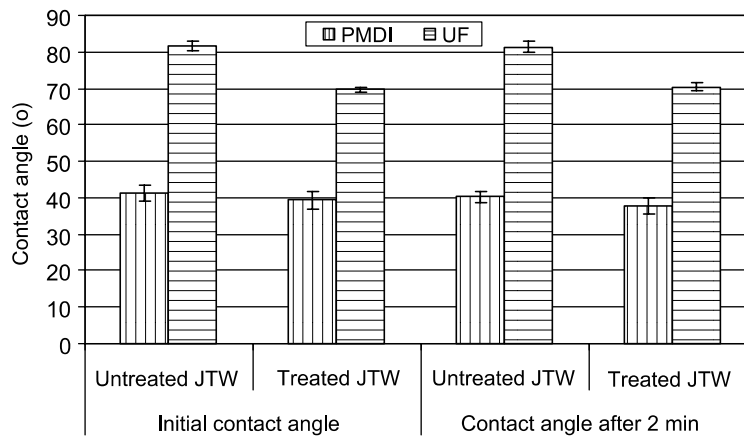


Fig. 1. Contact angle between JTW inner surface and UF or PMDI.

more significant than for PMDI. However, the quality of particleboards with treated particles was not improved even though the contact angle was decreased. For both PMDI and UF, the contact angle reduction was less than 1° after 2 min. This result indicated that the NaOH treatment did not enhance the wettability of the JTW surface.

#### 4. Conclusions

The JTW is a suitable material for making high quality PMDI-bonded particleboards. The qualities of PMDI-bonded particleboards were improved as the density of finished particleboards was increased. Particleboards with density of 0.73 g/cm<sup>3</sup> or higher exceeded the minimum mechanical property requirements in MOR, MOE, and IB for type M-2 particleboard for industrial applications, based on US Standard ANSI/A208.1. In the tested range of initial MC (2–10%) of the particles, 8% MC resulted in the best qualities of PMDI-bonded particleboards. The UF-bonded particleboards made from NaOH treated and untreated JTW had much lower qualities than the boards bonded with PMDI. The results of contact angles between JTW and adhesives showed better wetting between JTW and PMDI than that between JTW and UF. It was unexpected that the NaOH treatment reduced the qualities of the particleboards.

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